

PAPER • OPEN ACCESS

Numerical Simulation on the Flame Propagation in Duct-Vented Gas Explosion: The Effect of Duct Length on the Secondary Explosion

To cite this article: Siti Zubaidah Sulaiman *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **551** 012009

View the [article online](#) for updates and enhancements.

Numerical Simulation on the Flame Propagation in Duct-Vented Gas Explosion: The Effect of Duct Length on the Secondary Explosion

Siti Zubaidah Sulaiman¹, Nurul Syazwana Noor Azmi¹, Azizan Ramli¹, Rafiziana Md Kasmani², Siti Kholijah Abdul Mudalip¹, Rohaida Che Man¹, Shalyda Md Shaarani¹, Zatul Iffah Mohd Arshad¹

¹Faculty of Chemical and Natural Resources Engineering, Universiti Malaysia Pahang, 26300 Kuantan, Pahang, Malaysia

²Faculty of Chemical Engineering & Energy Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Malaysia

E-mail: szubaidah@ump.edu.my

Abstract. Duct venting is the most recognized explosion protection technique used in the industry. However, the key problem with this technique is the appropriate design of the duct size for an effective release material to prevent the secondary explosion that can cause further damage to the plant. Factors such as duct length and diameter have a significant effect on the duct venting mechanism that contributes to the second explosion. Thus in this study, the duct-vented gas explosion was simulated with the aim to investigate the influence of duct length focusing on the flame and pressure characteristics. From the simulation analysis, it shows that vessel interconnected with the duct with 0.05 m diameter and 0.5 m length experience a flame severe problem behavior to produce the secondary explosion effect.

1. Introduction

In theory, when an explosion event occurs in the vessel/pipe, the pressure will rapidly increase until it reaches the static pressure (vent panel pressure). This condition may cause the vent panel to rupture and allow the hot materials to be released from the vessel/pipes through vent duct. During the venting process, the unburnt gases (hot materials) flow at high velocity, causing it to choke. It then increases the amount of trapped unburnt gases inside the vessel and the duct [1]. The secondary explosions are the result of unburnt gases accumulation inside a duct re-ignited by the flame front. The secondary explosion mechanism inside the duct causes a backflow towards the main vessel and the interaction with the flame front will generate turbulent pressure wave and thus, enhancing the pressure inside the main vessel that eventually leads to detonation [1].

One of the major factors affecting flame and pressure characteristic that contributes to the strong explosion is a duct size [2]. Iida et al., 1985 has observed the flame and pressure characteristic in a smaller duct size (diameter: 5cm and length: 10 cm). They reported that fast flame or self-flame accelerations by the complex interaction between quenching effect and re-ignition process will lead to the violent secondary explosion [3]. Other studies supported the above hypotheses by using relatively narrow ducts (diameter: 5 cm and length: 10-20 cm) with a sharp vessel-duct area[4-6]. It was shown that the turbulent flame enhance the secondary explosion (i.e. with higher pressure amplitudes) during re-ignition [1]. Moreover, the effect of the duct size towards the secondary explosions was analyzed by



the Baraldi et al., 2010 [7]. They reported that the secondary explosion occurred due to the reversal flow where the flame will travel backwards from duct to the main vessel, enhancing the burning rate by means of rapid pressure rise in the vessel and leads to the extensive damage[7].

From the above research on the vented gas explosion inside the duct that has been studied, most of the works are limited to smaller duct size with the length ranging from, 10-80 cm respectively, which does not represent the actual duct size in the industry. It should be noted that, beyond the limit, secondary explosion mechanism, as well as flame and pressure characteristics in the duct, will be different. Changing the duct length may change the flame behavior and hence, increasing the mass burning rate of spherical flames[7]. This would directly influence the flame and pressure characteristics in the duct venting. Therefore, in this study, the influence of duct length was studied thoroughly, as it has been recognized as factors contributing to the secondary explosion in a duct.

2. Experimental

The biogas flame propagation was simulated using ANSYS Fluent R16.2. The effect of the duct length towards the explosion pressure and flame speed for both vessels with and without duct were analyzed. The duct diameter was fixed at 0.05 m and three lengths; 0 m, 0.5 m and 1.0 m were varied in this work. In order to simulate the venting process, the geometry is divided into two part (Part A and Part B) as shown in figure 1. Part A is a vessel, a place where the explosion occurred. Part B is a duct interconnected with the vessel. In this research, the biogas-air mixture was used at stoichiometric concentration for the explosion scenario.

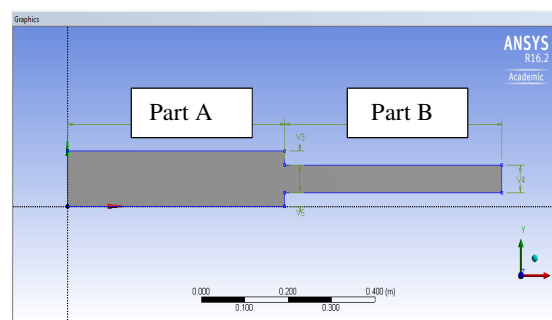


Figure 1. Geometry of the computational domain with surface body in Design Modeler.

The numerical model of premixed combustion was adopted in this study. Two-dimensional (2D) model was used and it was assumed that the turbulent flame is propagating under transient conditions. In this study, the premixed combustion model was used in which the fuel and oxidizer were mixed at the molecular level prior to ignition. The spark energy was applied to ignite the mixture. Carbon steel was used as the type of vessel wall. The operating condition was set up at the atmospheric condition and room temperature.

3. Results and Discussions

3.1. Effect of duct length on the pressure

Figure 2 shows the effect of three different duct lengths; 0m (ductless), 0.5m and 1.0m on the pressure. From the figure, it is clearly shown that the pressure trend was different for all ducts length. For instance, there are two pressure peaks were observed at duct length 0.5 m instead of 1 pressure peak at duct length 1 m, while the pressure in a ductless vessel just increases gradually without any distinct peak. To be noted, the 1st pressure peak was occurred due to the flame propagation into the duct. The second peak

was suspected due to the secondary explosion. The overall pressure trend can be described based on the vented gas explosion mechanism (refer to figure 3). During the venting process, the unburnt gases (hot materials) flow from the vessel to the duct at high velocity, causing it to choke. It then increases the amount of trapped unburnt gases inside the vessel and the duct. When the flame propagated into the duct, it will ignite the unburnt gases leading to the external explosion [1]. This phenomenon caused to the increase of the pressure at all duct length as indicates in figure 2 (1st pressure peak).

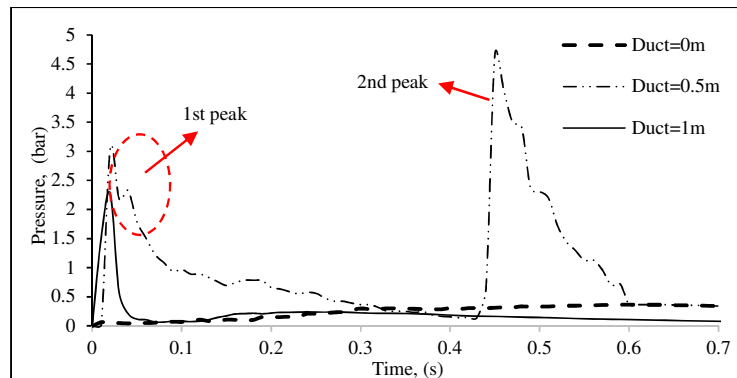


Figure 2. Pressure versus time for biogas-air mixtures at three different duct lengths.

However, the secondary pressure peak which was observed at duct length 0.5 m, was suspected due to the complex interaction between trapped unburnt gas-flame. During the external explosion, the pressure at the duct will be increased as compared to the vessel. At this instance, the flame will propagate back towards the main vessel and ignite with the trapped unburnt gas. This ignition will generate turbulent pressure wave and thus, enhancing the pressure inside the main vessel that eventually leads to secondary explosions. However, the second mechanism is not featured at duct length 1 m since there is only one pressure peak was recorded (see figure 2). The peculiar trend was suspected due to the heat loss to the duct wall. Increase the duct length from 0.5 m to 1.0 m leading to the increase of the heat loss to duct wall giving the intensity of the external explosion to be lesser which resulted to the weak reversal flow and no significant effect to the secondary explosion[1].

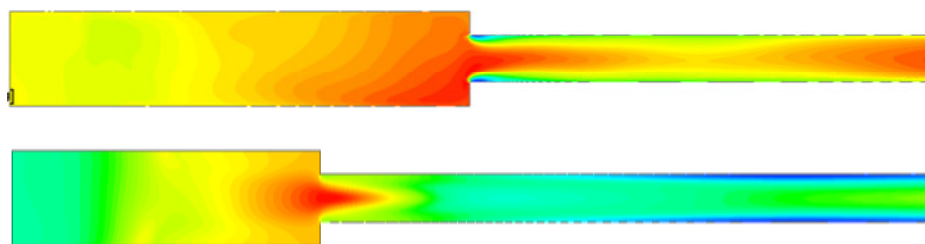


Figure 3. Flame propagation in duct venting: duct length 0.5 m (top) and 1 m (bottom).

3.2. Effect of duct length on flame speed

Figure 4 shows the flame speed trend in three different duct length ranged within 0 (ductless) to 1 m. It is clearly shown that the flame speed trend is comparable with all duct length. The flame speed increase before decreasing and later seed-up until reach to the highest flame speed at the third peak except for ductless. According to Zheng (2018), the flame acceleration is due to the flame stretch caused by the thermal expansion of the combustion product. Once the flame is stretch it will increase the flame surface area and cause to the increase of mass burning rate before. At this instance, flame starts to accelerate. However, the acceleration stops as the flame front touches to the sidewalls due to the quenching effect.

At this situation, the flame starts to stabilize, reduce the flame surface area and start to decelerate as represented by the first peak in figure 4. However, since the flame is kept propagating, it makes the flame surface area increase and start to re-accelerate until it reaches the highest speed before it starts to decrease as indicated in the second peak. The decreasing of the flame speed shows that the unburnt gas is completely burning.

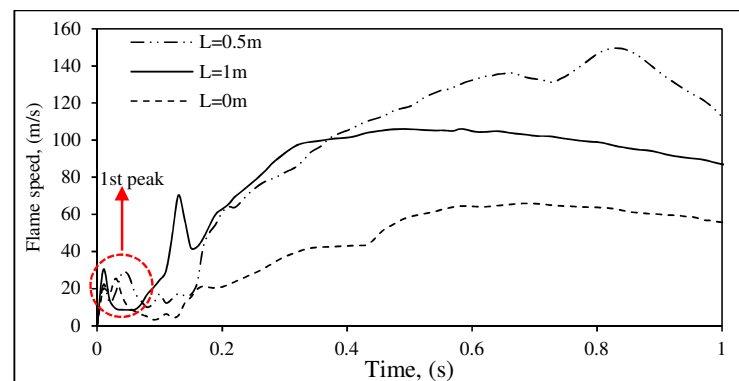


Figure 4. Flame speed versus time for biogas-air mixtures at three different duct lengths.

Furthermore, the highest flame speed was attained at the vessel connected with the 0.5 m length duct with the flame speed; 146.2 m/s followed by duct length 1 m (105.8 m/s) and 0 m ducts with the flame speed 37.43m/s respectively. It is clearly shown that, the shorter the duct length, the higher the flame speed. As mention earlier the quenching effect or heat loss to the wall play a major role on the flame propagation. At 1 m duct length, more heat losses to the wall cause the flame to quench. The quenching effect makes the turbulent flame to become more stable and then decelerates to about 28% as compared to the duct with 0.5 m. It is clearly shown that venting interconnected with the duct length 0.5 m giving worst case scenario which can result to the secondary explosion. and start to re-accelerate until it reaches the highest speed before it starts to decrease as indicated in the second peak. The decreasing of the flame speed shows that the unburnt gas is completely burning.

4. Conclusions

From the research, we can conclude several conclusions which are;

- i. The complex interaction between trapped unburnt gas and flame is the main mechanism triggering to the secondary explosion incident.
- ii. The quenching effect or heat loss to the wall play a major role on the turbulent flame which can lead to the secondary explosion effect.
- iii. Vessel interconnected with the 0.05 m diameter and 0.5 m length duct experience the severe flame behavior that triggering to the secondary explosion.

References

- [1] Zhang Q et al 2013 *Journal of Loss Prevention in the Process Industries* **26** 1230.
- [2] Ponizy B et al 1999 *Combust Flame* **16** 259.
- [3] Zhen Y et al 2018 *Journal of Fire Sciences* **36** 164.
- [4] Kim N I et al 2006 *Combustion and Flame* **146** 283.
- [5] Li J et al 2006 *Shock Waves* **16** 109.
- [6] Salzano E et al 2002 *Journal of Hazardous Materials* **95** 233.
- [7] Baraldi D et al 2010 *International Journal of Hydrogen Energy* **35** 12381.